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Atmospheric Physics Lab Work

Differential Mobility Particle Sizer (Aerosol measurements)

Abstract

A differential mobility particle sizer (DMPS) is a standard tool in atmospheric science to measure the particle size distribution in the sub-micron size range. In this experiment, a DMPS is used to measure the aerosol size distribution of two particle sources: A candle and urban air. Both size distributions are analyzed and compared to each other.

Questions to be answered during the reading of the manual

(Will be discussed in a small tutorial ahead of the experiment)

- Why is the particle size important for ambient air?
- Why need the particles to be charged in order to be measured with this technique?
- What happens if particles carry multiple charges?
- Can you think of other techniques to measure particle sizes? For which sized may they be best suited and why?

Please finish the following exercises before the day of the experiment:

- Consider the formulas and calculate the min/max size range from the possible voltages. (Hint: It is simplest to do this graphically. Plot the voltage as a function of the particle diameter. Get the size range from this linear plot).
- Divide the size range into size bins (e.g. 10 per decade).
- Calculate the appropriate voltage for each size.

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1. Introduction

Aerosols are liquid or solid particles suspended in a gas. Aerosols in the atmosphere can have both natural and anthropogenic sources. Besides air pollution and health effects atmospheric aerosols are an important factor in climate effects, especially with respect to the radiation budget of the atmosphere. In addition to light scattering in the atmosphere, as in the case of fog or smog, they can directly scatter solar radiation back to space and therefore cause radiative cooling (direct aerosol effect). Furthermore, aerosols can act as cloud condensation nuclei leading to cloud formation. The radiative properties of the clouds depend on the number and type of aerosol (indirect aerosol effect).

The size range of atmospheric aerosols is from about 10 nm to 100 µm. Thereby, particles in the order of 0.1-1µm are a matter of particular interest since they have the highest scattering intensities, longest atmospheric lifetimes and are the majority of cloud condensation nuclei. The size distribution of polydisperse aerosols can be determined with a DMPS System (Differential Mobility Particle Sizer). A DMPS consists of a DMA (Differential Mobility Analyzer) transmitting only particles with a certain size, and a CPC (Condensation Particle Counter), counting these particles. In this lab experiment, the size distributions of different types of aerosol particles will be determined with a DMPS system. The setup is shown in Figure 1.

2. Instruments

2.1. DMA and electrical mobility

A DMA separates charged particles according to their electrical mobility. Electrically charged particles move in the electrical field according to their electrical mobility. The DMA is a

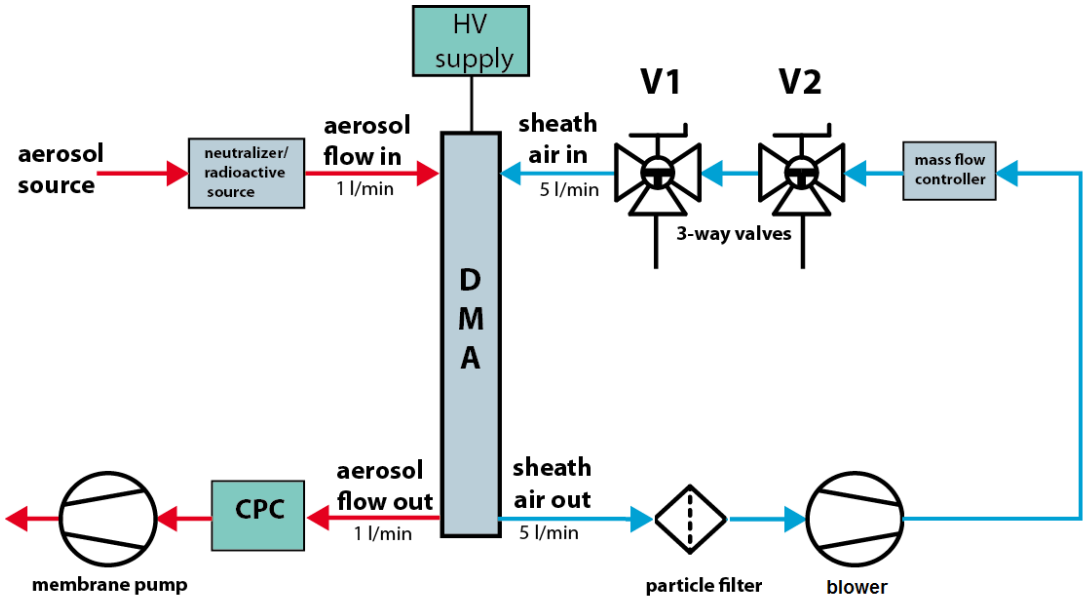

Figure 1: Experimental setup

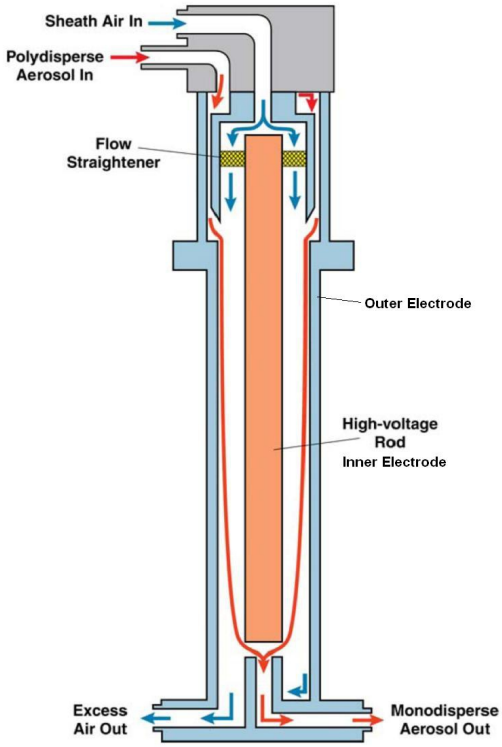

Figure 2: Differential Mobility Analyzer, Figure from TSI

cylindrical capacitor consisting of an inner electrode (HV-Rod) and an outer electrode, (Figure 2). The incoming sample flow containing the polydisperse aerosol (Polydisperse Aerosol In) is directed (together with laminar particle-free sheath) air parallel to the HV-Rod. The horizontal particle velocity is:

$$v = Z_p E \tag{1}$$

where v is the particle velocity, and Z_p the electrical mobility and E is the field strength. The electrical mobility of a particle is defined as the ratio of the constant limiting velocity a charged particle will reach in a uniform electric field to the magnitude of this field [Willeke and Baron]. The electrical mobility depends mainly on the particle size and electrical charge. The smaller the particle and/or the higher the electrical charge the higher is the electrical mobility. The electrical mobility is in general given in dependence of the particle diameter dp by

$$Z_p = \frac{n e C_c(d_p)}{3 \pi \eta d_p} \tag{2}$$

where C_c is the Cunningham slip correction which is a correction to the friction for particles between the continuum and free molecular regime.

$$C_c = 1 + \frac{2\lambda}{d_p}\left(1.142 + 0.558 \exp\left(-\frac{0.999\, d_p}{2\lambda}\right)\right) \tag{3}$$

The electric mobility in a DMA for a certain deposition location can be described by the following equation

$$Z_p = \frac{q_c + q_m}{4\pi\Lambda V} \tag{4}$$

where q_c is the flow of sheath air at the DMA entry and q_m the sheath air flow at the DMA exit [Knutson and Whitby]. V is the voltage between inner and outer rod and Λ is an instrument constant given by

$$\Lambda = \frac{L}{\ln\left(\frac{r_{inner}}{r_{outer}}\right)} \tag{5}$$

where L is the DMA length, r_{inner} the radius of the inner electrode from the DMA capacitor and r_{outer} the radius of the outer electrode from the DMA capacitor, i.e. the inner radius of the DMA cover. Depending on their polarity the particles are accelerated either to the outer or the inner electrode. The particles whose deposition place (at a certain voltage, i.e. electrical mobility) matches the position of the gap at the outlet of the DMA (Figure 2) pass the DMA, i.e. are size classified. The transmitted particles satisfy the following mobility-voltage relationship which can be derived from equations (2) and (4):

$$V = \frac{3\eta q_c}{2neA} \frac{d_p}{C_c(d_p)} \tag{6}$$

By ramping the DMA voltage, the selected particle diameter can be changed. The DMA used in this experiment has the following dimensions: L = 44.37 cm, r_{inner} = 9.37 mm and r_{outer} = 19.61 mm. Further, it can be assumed that for air at room temperature the mean free path is $\lambda = 66.5\,\text{nm}$ and the viscosity $\eta = 1.83 \cdot 10 - 5\,\text{Nsm}^{-2}$.

2.1.1. Neutralizer

Before the particles enter the DMA they pass through a neutralizer. The neutralizer does not neutralize charges, but rather brings the particles into a well-known charge distribution with a radioactive polonium source. The result is a Boltzmann distribution of negative and positive charged particles. In an electric field a particle with n charges experiences an electric force, causing it to move through the gas in which it is suspended.

2.2. Condensation Particle Counter (CPC)

The CPC counts the aerosol particles that pass through the DMA. Inside a CPC, incoming particles are enlarged due to vapor condensation so that they are big enough for later detection. This is done in a heated saturator where alcohol vapor condenses onto the particles, causing them to grow into droplets. These droplets are then detected with a laser beam (Figure 3). The working fluid in the CPC (TSI, Model 3010) used in this experiment is n-butanol. The instrument detects particles between 10 nm and 3 µm. Single particles are detected for concentrations lower then $10^4\,\text{cm}^{-3}$. For higher concentrations the particle number is estimated from the scattered laser light. The sample flow of the instrument is $1\,\text{l min}^{-1}$.

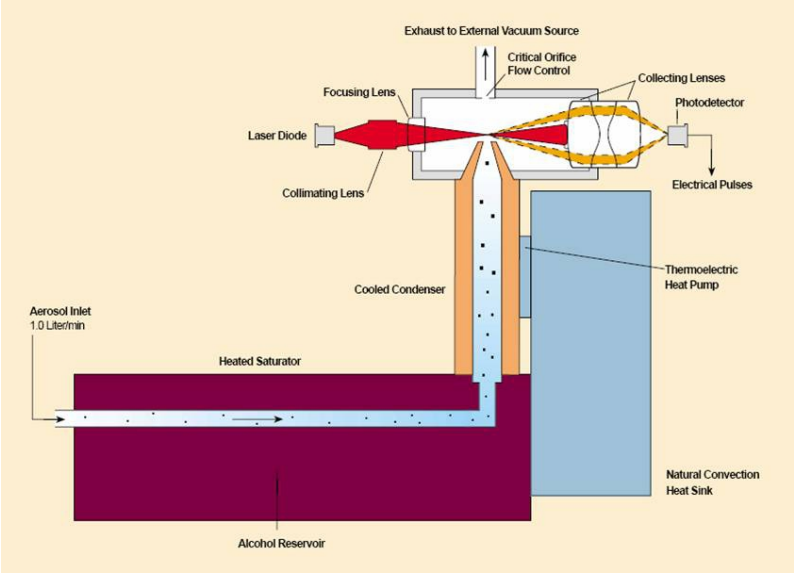

Figure 3: Condensation Particle Counter, Figure from TSI

2.3. Differential Mobility Particle Sizer (DMPS)

A DMPS consists of a DMA and a CPC. Particles are first size selected with the DMA and then counted with the CPC.

2.4. Flowmeter

A flow meter is an instrument for measuring and calibrating volume flows of gases. The Gilibrator instrument (Figure 4) we use in this experiment works with a soap bubble rising with the flow. It measures air flows in both directions. i.e. in a sucking or blowing mode. It is important that incoming air enters the lower hose connection and exits the upper connection. At the base of the flow cell is a bubble generator. By pushing the button down, a ring lowers

Figure 4: Gilibrator flowmeter

itself into the soap solution, creating a film. Releasing the button lifts the film to the flow tube and it rises with the air stream. Sensors measure the velocity of the bubble and the volume flow rate is calculated. Note, that the Gilibrator measures volume flows. To compare these flows e.g. to a Mass Flow Controller, volume flows have to be temperature- and pressure-compensated using the ideal gas law.

3. Practical advice

3.1. DMA flow checks

Disconnect the CPC before calibrating the DMA flows!

When changing tubing connected to the CPC always switch off the CPC pump before!

The sheath- and sample flows of the DMA used in the experiment need to be controlled prior to the experiment as the selected particle diameter directly depends on the air flow. First of all, the sheath air in the DMA system must be set to 5 l min^{-1} in the labview program. The flow is then measured using the Gilibrator Flowmeter.

The DMA sheath flow system is a closed loop. Air is sucked by a blower from the lower exit of the DMA (excess air out) and passes a filter. A mass flow controller upstream of the blower regulates the flows and is controlled by a labview program. After passing the two 3-way valves the particle free air enters the DMA again (sheath air in).

Before starting, disconnect the CPC!

First, block the DMA polydisperse aerosol in line as well as the monodisperse aerosol out line. Turn both 3-way valves so that they point outwards. Start the labview program and set the sheath flow to 5 l min^{-1}. The blower will now suck air from the 3-way valve V1, then through the DMA and finally release it at V2. Measure with the Gilibrator Flowmeter if the inlet flow at V1 equals the exhaust flow at V2. You should see only little differences.

Next, measure the flow of the CPC by starting its pump and connecting the flowmeter right at its inlet.

Finally, in order to check if leaks or blockages are present in the system, measure the aerosol flow upstream of the neutralizer. For that, unblock the DMA aerosol in and out lines and connect the CPC to the aerosol out line. Switch on the CPC pump and measure the aerosol flow with the flowmeter. You should not see a strong deviation from 1 l min^{-1}.

3.2. Delay time

Particles need some time to pass from the DMA entrance to the CPC. This delay time needs to be determined so it can be added to all further measurements. To measure the delay time a filter can be connected upstream of the DMA entrance. When the concentration at the CPC has dropped to zero remove the filter. The time it takes now until incoming particles have reached the CPC and its readout shows a concentration settled at a stable level is called the time lag.

4. Experiments

4.1. Exercises

After the flows have been adjusted and the instrument has been brought to a working state the size distributions of aerosol particles can be measured. In this experiment the size distribution of the aerosols which a standard tea light candle produces shall be compared to the size distribution of ambient urban aerosols. Perform all experiments twice to have two size distributions for comparison.

4.2. Candle

The candle stands inside a glass volume so that the aerosols it produces are not diluted. The ventilator is used to distribute the aerosols equally in the volume. Since the candle needs a lot of oxygen add a flow of 10 l/min of filtered compressed air to the volume. Mount the tubes into the volume and ensure that the sampling tube is fixed in the upper part. Wait until the candle burns stable before you start sampling. Monitor the CPC concentration at one of your smaller size bins to ensure a stable concentration has been reached. Measure the concentration step by step for all of your size bins to obtain the full size distribution. Note that your measurements should start only after the delay time.

4.3. Urban air

Do exactly as before for ambient air. Use appropriate tubing (conductive, i.e. black silicone or metal tubing) to sample from outside the window.

4.4. Report

Your report should have the following structure:

- Summary of the theory
- calculation and table of voltage vs. diameter
- Complete measurement report including graphics
- Derivations and interpretations
- Results and discussion
- Calculation of errors

5. References

- Instruction Manual: Model 3010 Condensation Particle Counter; 2002, TSI Incorporated, St. Paul, MN, USA.
- Operation and Service Manual: Series 3080 Electrostatic Classifiers; 2006, TSI Incorporated, St. Paul, MN, USA.
- E. O. Knutson and K. T. Whitby (1975). Aerosol classification by electric mobility: Apparatus, theory, and applications. J. Aerosol Sci. 6: 443-451.
- K. Willeke and P.A. Baron: Aerosol Measurement, Van Nostrand, 1993